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Center for Electronics and Electrical Engineering

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INTRODUCTION TO APRIL 1984 (3) ISSUE OF THE CEEE TECHNICAL PROGRESS BULLETIN

This is the fifth issue of a quarterly abstract journal covering the work of the National Bureau of Standards Center for Electronics and Electrical Engineering. This issue of the CEEE Technical Progress Bulletin covers the fourth quarter of calendar year 1983.

ORGANIZATION: Abstracts and citations are arranged by technical topic as identified in the table of contents and alphabetically by first author under each subheading within each topic. Each abstract ends with a telephone number of the individual to contact for more information on the topic; unless otherwise noted, this individual is the first author. Each citation ends with identification of the issue of the Technical Progress Bulletin in which the associated abstract appeared. This issue also includes a calendar of Center conferences and workshops for the remainder of calendar year 1984, an announcement of newly released standard reference materials, and a list of sponsors of the work. SPECIAL NOTE: Because the four issues covering calendar year 1983 are later than intended, the contents of these issues will differ from the original plan of providing abstracts for all papers released by NBS in a quarter as follows: Each issue will contain (1) abstracts of papers released for publication by NBS for the appropriate quarter and not subsequently published until calendar year 1984, (2) abstracts of papers released and published during the quarter, and (3) citations for papers published during the quarter, but for which abstracts have appeared in an earlier issue of the Technical Progress Bulletin. Items in category (1) appear under the subheading "Released for Publication"; items in categories (2) and (3) appear under the subheading "Recently Published".

Center for Electronics and Electrical Engineering: Center programs provide national reference standards, measurement methods, supporting theory and data, and traceability to national standards.

The metrological products of these programs aid economic growth by promoting equity and efficiency in the marketplace, by removing metrological barriers to improved productivity and innovation, by increasing U. S. competitiveness in international markets through facilitation of compliance with international agreements, and by providing technical bases for the development of voluntary standards for domestic and international trade. These metrological products also aid in the development of rational regulatory policy and promote efficient functioning of technical programs of the Government.

The work of the Center is divided into two major programs: the Semiconductor Technology Program, carried out by the Semiconductor Materials and Processes and Semiconductor Devices and Circuits Divisions in Gaithersburg, MD, and the Signals and Systems Metrology Program, carried out by the Electrosystems Division in Gaithersburg and the Electromagnetic Fields and Electromagnetic Technology Divisions in Boulder, CO. Key contacts in the Center are given on the back cover; readers are encouraged to contact any of these individuals for further information.

Previous special issues: Two special issues of the Technical Progress Bulletin have been published with abstracts for the Signals and Systems Program only, NBSIR 83-2719-1, covering October 1981 through March 1982 and NBSIR 83-2719-2, covering April 1982 through September 1982. NBSIR 82-2636, a special issue of the Semiconductor Technology Program Progress Briefs published in January 1983, listed abstracts of publications from that Program for Federal fiscal year 1982 (October 1981 through September 1982, fifty-third through fifty-seventh quarters of the Program). The new CEEE Technical Progress Bulletin replaces the Progress Briefs series [single copies of 82-2636 are available from the Center, see back cover for address].

Center sponsors: The Center Programs are sponsored by the National Bureau of Standards and a number of other organizations, in both the Federal and private sectors; these are identified on page 18.

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SEMICONDUCTOR TECHNOLOGY PROGRAM

Silicon Materials

Released for Publication

Forman, R.A., Bell, M.I., Mayo, S., and Kahn, A.H., **The Effect of Spatial Averaging on the Compositional Analysis of Crystals by Absorption Spectroscopy**, submitted to J. Applied Physics.

Calculations of optical absorption based on a model of a single crystal containing periodic compositional variations are presented. These variations can contribute a significant source of systematic error in the analysis of composition by optical or surface techniques. The model is most appropriate for melt-grown crystals and in particular for striated semiconductor crystals. The results are discussed in the context of optical absorption studies of impurities in typical semiconductor silicon crystals and it is shown that significant measurement errors may occur.
[(301) 921-3625]

Recently Published

Forman, R.A., Bell, M.I., Baghdadi, A., and Mayo, S., **The Effects of Striations on the Compositional Analysis of Silicon Crystals**, Defects in Silicon, Proc. 83-9, pp. 303-312, W. M. Bullis and L. C. Kimerling, Eds., Electrochemical Society, Pennington, NJ (1983) [paper presented at Society conference, San Francisco, CA, May 8-13, 1983; summary published in Extended Abstracts of the Electrochemical Society, 83-1, pp. 463-464 (1983); abstract appeared on page 2 of July 1983 TPB (NBSIR 83-2719-3)].

Larrabee, R.D. and Lowney, J.R., **Measurement Techniques for High-Resistivity Detector-Grade Silicon: Progress Report, July 1, 1982 to June 30, 1983**, NBSIR 83-2792 (December 1983).

Techniques for nondestructively characterizing the resistivity and excess-carrier recombination lifetime in ingots of high-resistivity, long-lifetime detector-grade silicon are being evaluated. In particular, three interrelated techniques for nondestructively: 1) measuring an average resistivity, 2) profiling the low-level excess-carrier lifetime, and 3) profiling the resistivity of cylindrical ingot specimens are proposed and are in the process of being evaluated. All three techniques treat the ingot under test as a large van der Pauw specimen and require removable silver-paste contacts or pressed-on capacitive contacts. The profiling measurements utilize a highly penetrating 1.15-μm He-Ne laser beam as an optical probe. The conceptual and theoretical background for these measurements and the results of feasibility experiments obtained to date are presented. These results show the expected behavior and produce reasonable results, but additional work is required to complete the feasibility experiments and to confirm the results on a few specimens by some independent technique.
[(301) 921-3786]

Phillips, W.E., Thurber, W.R., and Lowney, J.R., **Improved Analysis Procedures for Deep-Level Measurements by Transient Capacitance**, Defects in Silicon, Proc. 83-9, pp. 485-490, W. M. Bullis and L. C. Kimerling, Eds., Electrochemical Society, Pennington, NJ (1983) [paper presented at Society conference, San Francisco, CA, May 8-13, 1983; summary published in Extended Abstracts of the Electrochemical Society, 83-1, pp. 467-468 (1983); abstract appeared on page 2 of July 1983 TPB (NBSIR 83-2719-3)].

Gallium Arsenide Materials

Released for Publication

Pande, K.P. and Seabaugh, A.C., **Low**

Gallium Arsenide Materials, cont'd.

Temperature Plasma-Enhanced Epitaxy of GaAs, submitted to J. Electrochemical Society.

Metal line structures with intentional defects in the passivation, to simulate cracks or voids, were used in electromigration studies. Results show that the stress gradients caused by these defects are not as important as the restraining action of the passivation in affecting a metallization's susceptibility to electromigration failure. Also, the observed effects of restorative forces acting on the metallization suggests that continuous monitoring for open-circuit failure may be necessary to obtain an accurate measure of the mean-time-to-failure.
[Contact: Seabaugh, (301) 921-3625]

Analysis Techniques

Recently Published

Baghdadi, A., **Multiple Reflection Corrections in Fourier Transform Spectroscopy**, Defects in Silicon, Proc. 83-9, pp. 293-302, W.M. Bullis and L.C. Kimerling, Eds., Electrochemical Society, Pennington, NJ (1983) [paper presented at Society conference, San Francisco, CA, May 8-13, 1983; summary published in Extended Abstracts of the Electrochemical Society, 83-1, pp. 460-461 (1983) under title **Multiple Reflection Corrections in Fourier Transform Spectroscopy of Back Surface Damaged Wafers**; abstract appeared on page 2 of July 1983 TPB (NBSIR 83-2719-3)].

Insulators and Interfaces

Recently Published

Chandler-Horowitz, D. and Candela, G.A., **On the Accuracy of Ellipsometric Thickness Determinations for Very Thin Films**, J. de Physique 44, pp. C10-23 (December 1983).

The uncertainty in the ellipsometric determination of the thickness of a film on a substrate can be found quantitatively. We have used the solution of the differentials of film thickness and refractive index. Results of calculations for the air-SiO_2-Si system are presented. This theory has been used to calculate the uncertainty in the value of the thickness as a function of wavelength. We have also calculated this uncertainty for known uncertainty in the film's refractive index. We show which uncertainties contribute the most to the overall accuracy of a thickness measurement. [(301) 921-3561]

Dimensional Metrology

Released for Publication

Nyyssonen, D., **National Bureau of Standards, A Review of NBS's Activities in the Area of Linewidth Measurement**, to be published in Conference Summary, Future Trends in Optical Technologies in the Semiconductor Industry, May 23, 1983, Scientific Apparatus Manufacturers Association, Sunnyvale, CA.

Describes current NBS activities in linewidth measurement, including research, calibration of standard reference materials (SRMs), development of calibration procedures and test methods, and technology transfer. The current status of photomask linewidth SRMs is discussed (anti-reflective "gold" chromium SRMs 474 and 475, bright chromium SRM 476, and the 3X reticle SRM 1830). Wafer linewidth measurements are divided into two categories, thin layers (less than approximately 200 nm) and thick layers. The design of the linewidth standard for thin layers is described. Research problems remaining for thick layers are described along with current NBS waveguide modeling. Instrumentation used for both photomask and wafer calibrations is also described. NBS plans for development of SEM/e-beam instrumentation and SRMs are also included. [(301) 921-3786]

Integrated Circuit Test Structures

Released for Publication

Suehle, J.S., Linholm, L.W., and Kafadar, K., **Minimum Test Chip Sample Size Selection for Characterizing Process Parameters**, to be published in Joint Special Issue of IEEE Trans. Electron Devices and IEEE J. Solid State Circuits.

A method for determining a test chip sample size to estimate effectively the electrical parameter distributions on an integrated circuit wafer is presented. This method gives relations among sample size and the figure of merit for four statistical techniques (trimmed mean, biweighted mean, median, and arithmetic mean) by which estimates are calculated. To demonstrate the use of this method, it has been applied to the evaluation of a CMOS fabrication process. Measurements on wafers completely patterned with identical test chips were used to determine actual parameter distributions for an entire wafer (true parameter values). Estimates of true parameters were determined using a site selection plan which is representative of sampling plans employed in industry. The above four statistical techniques were used to compute estimates for electrical parameters and their respective figures of merit. These estimates were compared with the true parameter values determined from testing all test chips on the wafer. When this method is used in conjunction with the cost criteria for test chip sample size, it enables judgments to be made on the effectiveness of sampling strategies for various processes and process technologies. The results reported in this paper for CMOS processes are interpreted for the case when no sample size cost criteria are given.
[(301) 921-3621]

Recently Published

Mattis, R.L. and Zucker, R., **Release Notes for STAT2 Version 1.31: An Addendum to NBS Special Publication 400-75**, NBSIR 83-2779 (November 1983).

This document describes the changes which have been made in the STAT2 computer program. The new version contains several new features which provide a more powerful data base capability, improved displays, and greater compatibility with the automatic tester. In going from the original version 1.01 to version 1.31, the DATA array has been redefined and new REA command formats have been added to be compatible with new data acquisition equipment. A new circular shaded map has been added which gives a more realistic representation of data variation over a wafer surface. New map and histogram scaling options allow greater flexibility in specifying the scale of data displays. A new format for two data base commands allows greater flexibility in selectively listing and correlating data base entries. The capability has been added for disabling warning messages to reduce unwanted printout, and for creating macro command files within a STAT2 run. Finally, a new method of specifying the directory containing the Help files makes STAT2 easier to install. Following the description of the changes is an annotated listing of new error messages.
[(301) 921-3621]

Mazer, J.A., Linholm, L.W., Pramanik, D., Tsai, S., and Saxena, A.N., **Comparison of Aluminum-Silicon Contact Resistance Values Obtained by Contact Chain and Kelvin Measurement Structures**, Extended Abstracts of the Electrochemical Society, 83-2, pp. 453-454 (Abstract 292) [paper given at Society conference, Washington, DC, October 9-14, 1983].

The characterization of metal/semiconductor ohmic-contact resistance by means of a two-terminal contact chain is limited to a non-Kelvin determination of front contact

Integrated Circuit Test Struct., cont'd.

resistance. The use of a microelectronic test structure and electrical measurement method for the Kelvin determination of front contact resistance determined by this method and by the contact chain method demonstrates inherent inaccuracies associated with the contact chain method.
[(301) 921-3621]

Proctor, S.J., Linholm, L.W., and Mazer, J.A., **Direct Measurements of Interfacial Contact Resistance, End Contact Resistance, and Interfacial Contact Layer Uniformity**, IEEE Trans. Electron Devices, ED-30, pp. 1535-1542 (November 1983) [related paper **A Microelectronic Test Structure for Interfacial Contact Resistance Measurement**, presented by Linholm to the Flate-Plate Solar Array Project Photovoltaic Metallization Systems Research Forum, Calloway Gardens, GA, March 16-18, 1983].

A four-terminal microelectronic test structure and test method are described for electrically determining the degree of uniformity of the interfacial layer in metal-semiconductor contacts and for directly measuring the interfacial contact resistance. A two-dimensional resistor network model is used to obtain the relationship between the specific contact resistance and the measured interfacial contact resistance for contacts with a uniform interfacial layer. A new six-terminal test structure is used for the direct measurement of end contact resistance and the subsequent determination of front contact resistance. A methodology is described for reducing the effects of both contact-window mask misalignment and parasitic resistance associated with these measurements. Measurement results are given for 98.5% Al/1.5% Si and 100% Al contacts on n-type silicon.
[Contact: Linholm, (301) 921-3541]

Russell, T.J., Wilson, C.L., and Gaitan, M., **Determination of the Spatial Variation of Interface Trapped Charge Using Short-Channel MOSFETs**, IEEE Trans. Electron Devices, ED-30, pp. 1662-1671 (December 1983).

The charge-pumping measurement method for determining interface trapped charge (ITC) density was used to find the spatial distribution of ITC across a wafer using MOSFETs with different channel lengths. A charge pumping current is produced by repetitively pulsing the MOSFETs between accumulation and inversion. This current is proportional to the ITC density. Only the MOSFET gate length and width and the pulse frequency are required to calculate ITC density from charge pumping current. Two-dimensional simulation of the measurement is used to show that, for sufficient applied pulse height voltage, the correct area is obtained from the polysilicon physical gate length and width. This measurement is strongly dependent on variations in the polysilicon gate area. If the spatial variation of the physical gate length on the wafer is neglected, an incorrect interpretation of the spatial variation of ITC will result. In this experiment the gate lengths were assumed to be constant across the wafer and a systematic spatial variation in ITC with a range of $2.8\text{-}5.0 \times 10^{10}$ cm^{-2} was observed. After measuring the physical gate length for each device on the wafer and making a length correction to the area, there was no systematic variation in ITC and its range was $5.4\text{-}7.0 \times 10^{10}$ cm^{-2}. Length corrections were also made for the other two transistors at each location on the wafer and the ITC densities exhibited distinct ITC populations. The mean ITC density for each transistor was separated from the other populations by at least 2 standard deviations. Detection of this type of variation in ITC using capacitors is not possible since there is no known relation between ITC measured by MOS capacitors and ITC measured with MOSFETs.
[(301) 921-3621]

Yen, D., Linholm, L.W., Glendinning, W.,

Integrated Circuit Test Struct., cont'd.

Bass, J.F., and Cheville, D.E., **An Electrical Measurement Technique for Estimating Proximity Effects in Electron-Beam Lithography,** Extended Abstracts of the Electrochemical Society, 83-2, pp. 333-334 (Abstract 212) [paper given at Society conference, Washington, DC, October 9-14, 1983].

An electrical test structure and test method is described for estimating the magnitude of proximity effects in electron-beam lithography. The test structure consists of van der Pauw cross resistor for measuring sheet resistance, a bridge resistor for measuring electrical linewidth, and a second bridge resistor simulating a close line-space environment for measuring electrical linewidth where proximity exposure effects from nearby patterns may be encountered. These test structures were delineated in a metal layer on a silicon wafer using electron beam exposure and wet chemical etching. Electrical measurements are compared to optical measurements. This technique provides an alternative to optical measurements for determining effective linewidth in a dense circuit environment and can be used to estimate parameters for the double Gaussian model used in proximity correction algorithms.
[(301) 921-3621]

Process and Device Modeling

Released for Publication

Albers, J., **Semiconductor Measurement Technology: TXYZ: A Program for Semiconductor IC Thermal Analysis,** to be published as an NBS Technical Note.

A computer program, TXYZ, for the thermal analysis of semiconductor integrated circuits is presented and its applications are discussed. The program makes use of the closed form, analytic solution of the steady-state heat flow problem for a rectangular three-layer structure with multiple heat sources on the top layer. The temperature may be obtained for any point or set of points in the structure and is useful in the determination of the steady-state thermal response of IC chips and packages.
[(301) 921-3621]

Bennett, H.S. and Wilson, C.L., **Analysis of the Statistical Comparisons of Data on Band-gap Narrowing in Heavily Doped Silicon: Electrical and Optical Measurements,** to be published in J. Applied Physics.

A system of subroutines for iteratively reweighted least squares (IRLS) computations has been applied to the published measured and theoretical data on band-gap narrowing in heavily doped silicon. The data include electrical and optical measurements at room temperature, photoluminescence and optical measurements for temperatures below 35 K, and theoretical calculations at 300 K and 0 K. This procedure, IRLS, allows an unambiguous comparison of the various experimental and theoretical data in band-gap narrowing to be made. The results are 1) that the optical absorption data and theory are consistent at both 300 K and at temperatures below 35 K; 2) that the electrical and optical measurements are not consistent; and 3) that when compared with the low temperature optical absorption data, the photoluminescence data have low statistical significance.
[(301) 921-3541]

Recently Published

Albers, J., **The Relation Between the Correction Factor and the Local Slope in Spreading Resistance,** J. Electrochemical Society 130, pp. 2076-2080 (October 1983) [paper presented at Society conference, Washington, DC, October 9-14, 1983; summary published in Extended Abstracts of the Electrochemical Society, 83-2, pp. 514-515 (Abstract 323) (1983) under title **Investigation of the Relation Between**

Process & Device Modeling, cont'd.

the Correction Factor and the Local Slope in Spreading Resistance].

Dickey has proposed a technique, known as the local-slope method, for the calculation of the correction factor which is used to obtain resistivity profiles from spreading resistance data. The technique is founded upon two asymptotic models for the conduction process involved in the spreading resistance measurement for the cases of 1) a conducting layer over an insulating substrate, and 2) a high resistivity layer over a low resistivity, i.e., a conducting substrate. The results of these two extreme cases are bridged by means of an assumed functional relation between the correction factor and the local slope of the spreading resistance data. The two asymptotic models as well as the assumed functional relation between the correction factor and the local slope are examined. It is shown that the asymptotic models adequately describe the behavior of the correction factor for a thin uniform layer over insulating or conducting boundaries. In addition, the assumed single-valued behavior between the correction factor and the local slope which is assumed by the local-slope method is shown not to be an adequate representation of the multiple-valued relation between these two quantities found from multilayer data. For the cases considered, this distinction leads to an error in the resistivities interpreted by the local-slope method by as much as 60 percent. Nonetheless, the local-slope results qualitatively follow the multilayer results thus making the technique a usable one for the calculation of approximate correction factors. A comparison of the two correction factor vs. local-slope relations provides a basis for the behavior of the interpreted resistivities when they are compared with the input resistivities. [(301) 921-3621]

Albers, J., Roitman, P., and Wilson, C.L., **Verification of Models for Fabrication of Arsenic Source-Drains in VLSI MOSFETs**, IEEE Trans. Electron Devices, ED-30, pp. 1453-1462 (November 1983).

The understanding of the effects of both low- and high-temperature anneals of arsenic implanted into silicon is critical in the calculation of p-n junction profiles of sources and drains in short channel MOSFETs. The work reported here uses a self-consistent sample matrix of arsenic implanted into silicon over a wide range of fluences and annealed in both the low- and high-temperature regimes. This matrix of samples was measured by means of Rutherford back scattering (RBS), spreading resistance (Rsp), and secondary ion mass spectrometry (SIMS). The measurement techniques are compared with each other, with the predictions of ion implantation models, and with the annealing/diffusion models. Comparison of the RBS data from more than one experiment indicates that high quality quantitative analysis requires more complex calibration data for the detector than is usually available. The Rsp data obtained on the low-temperature annealed samples did not yield reasonable arsenic profiles, both with respect to the peak location and profile shape. The measurement technique which was most consistent with theoretical models and most reproducible from one experimenter to another is the SIMS technique. The SIMS data showed the best agreement with the TRIM Monte Carlo calculation of Haggmark and Biersack as well as the calculation of Winterbon when the low temperature data was used. In addition, calculation of the annealed profiles were found to be in agreement with the SIMS data, at temperatures greater than 900°C, when the form used by Fair was employed. A large adjustment in the parameters of the charge vacancy reaction is necessary; a much smaller adjustment is required in the parameters of the extrinsic diffusion reaction. The accuracy obtained here is typical of much

Process & Device Modeling, cont'd.

available data but may not be sufficient to characterize submicron structures. [(301) 921-3621]

Bennett, H.S., **Hole and Electron Mobilities in Heavily Doped Silicon: Comparison of Theory and Experiment,** Solid-State Electronics, 26, pp. 1157-1166 (1983) [related paper presented at Electrochemical Society conference, Washington, DC, October 9-14, 1983; summary published in Extended Abstracts of the Electrochemical Society, 83-2, pp. 542-543 under title **Inequality of Hole Mobilities in Heavily Doped N-Type and P-Type Silicon**].

Most device models for npn or pnp transistors assume that hole (electron) mobilities in n-type and p-type silicon are equal. Partial-wave phase shift calculations for the contributions of carrier-dopant ion scattering to the carrier mobilities lead to unequal minority hole (electron) and majority hole (electron) mobilities at the same doping density. These calculations are valid over the doping range of 2×10^{19} to 8×10^{19} cm^{-3} in n-type and p-type silicon and contain the assumptions that the holes and electrons move in isotropic, parabolic energy bands and are scattered by the screened Coulomb potentials of the dopant ions. When the effects of carrier-acoustic phonon and carrier-carrier scatterings are included, these calculations agree to within the spread of experimental values for the majority mobilities reported in the literature. This agreement is a substantial improvement by factors of 2 to 4 over the results of earlier theories such as first order Born and nondegenerate theories. The results of this work, particularly the inequality of minority and majority carrier mobilities, have implications for the modeling of both bipolar and field effect transistors. [(301) 921-3541]

Blue, J.L. and Wilson, C.L., **Two-Dimensional Analysis of Semiconductor Devices Using General-Purpose Interactive PDE Software,** IEEE Trans. Electron Devices, ED-30, pp. 1056-1070 (October 1983) and SIAM J. Scientific Computing, 4, pp. 462-484 (October 1983).

Analyzing currents and fields in VLSI devices requires solving three coupled nonlinear elliptic partial differential equations in two dimensions. Historically, these equations have been solved using a special-purpose program and batch runs on a large, fast computer. We use a general-purpose program and interactive runs on a large minicomputer. We discuss the physical formulation of the semiconductor equations and give three example solutions: a short-channel MOSFET near punchthrough, a DMOS power transistor in the ON state, and a beveled p-n junction. These examples demonstrate that solutions to a very general class of semiconductor-device problems can be obtained using these methods. [Contact: Wilson, (301) 921-3541]

Radiation Effects

Recently Published

Blackburn, D.L., Benedetto, J.M., and Galloway, K.F., **The Effect of Ionizing Radiation on the Breakdown Voltage of Power MOSFETs,** IEEE Trans. Nuclear Science, NS-30, pp. 4116-4121 (December 1983).

It is shown that the drain-source breakdown voltage of power MOSFETs is a strong function of the total dose of ionizing radiation to which the device has been exposed. For the n-channel MOSFETs studied, the breakdown voltage after exposure is reduced from the unirradiated value. The cause for the effect is postulated to be the trapping of radiation generated charge in the field oxide and the generation of traps at the field oxide-silicon interface. The devices studied varied in breakdown voltage between 60 to 500 V and used field plates and/or field rings to

Radiation Effects, cont'd.

terminate the high voltage junction. The magnitude of the drain-source voltage applied to the device during irradiation is shown to have a strong influence on the total shift in breakdown voltage after the irradiation. It is also found that the method of junction termination has some influence on the total shift. These influences occur because the electric field in the oxide during irradiation depends both upon the applied drain-source voltage and the method of junction termination. Implications of these findings on device applications are briefly discussed. [(301) 921-3541]

Lantz, M.D. and Galloway, K.F., **Total Dose Effects on Circuit Speed Measurements**, IEEE Trans. Nuclear Science, NS-30, pp. 4264-4269 (December 1983).

Measurements of propagation delay as a function of total ionizing dose were made using ring-oscillators, inverter chains, and NAND chains fabricated on the same CMOS test chip. The data illustrate the impact of the bias conditions of the MOS transistors during irradiation on the propagation delay time of the circuits. The data show no difference in propagation delay time for the three circuit types if comparable bias conditions are maintained during radiation exposure. The threshold voltage shift of the n-channel transistor in the "ON" state appears to be the dominant factor controlling the decrease in propagation delay as the total dose increased. The ultimate failure of the test circuits is due to the shift of the n-channel transistors to a negative threshold voltage. [Contact: Galloway, (301) 921-3541]

Power Devices

Recently Published

Chen, D.Y., Lee, F.C., Blackburn, D.L., and Berning, D.W., **Reverse-Bias Second Breakdown of High-Power Darlington Transistors**, IEEE Trans. Aerospace and Electronic Systems, AES-19, No. 6, pp. 840-847 (November 1983) [abstract appeared on page 5 of April 1984 TPB (NBSIR 84-2857-2)].

Packaging

Released for Publication

Oettinger, F.F., **Thermal Evaluation of VLSI Packages Using Test Chips -- A Critical Review**, Solid State Technology, 27, No. 2, pp. 169-179 (February 1984).

The design, analysis, and utilization of test chips for the thermal evaluation of VLSI packages are discussed. The factors that determine the thermal performance of microelectronic devices are the circuit type, the fabrication technology, the die size, the die attachment method, the package and heat dissipater design, and the ambient environment. Thermal test chips are extensively used in characterizing new package designs for VLSI chips in the 1- to 10-W range. The information discussed should allow the engineer to rationally choose a particular test chip design and to understand the implications of measurements to thermally characterize a particular chip-package system.

Recently Published

Harman, G.G., **The Microelectronic Ball-Bond Shear Test - A Critical Review and Comprehensive Guide to Its Use**, International J. Hybrid Microelectronics, 6, pp. 127-141 (October 1983) [also to appear in Solid State Technology].

The microelectronic ball-bond shear test was first developed in 1967. Since then, it has been used to study the effects of contamination on bondability, to characterize the reliability of gold-aluminum intermetallic formation, to control bonding machine parameters for device production, and to troubleshoot

Packaging, cont'd.

such production problems as poor metallization adherence and contamination. This paper critically reviews all of these uses and identifies ways that the shear test can be implemented to improve bond yield and assure long term bond reliability. A manual shear probe is described that can be quickly made from the blade of a jeweler's screwdriver. This probe was instrumented with a strain gage and the shear test results compared within 10% of those obtained from a machine. The paper also presents data obtained from shearing both aluminum-ball and -wedge bonds and determines how the shear testing machine requirements for these differ from those required to test gold ball bonds.

The shear strengths of both annealed gold and aluminum were measured and compiled in a plot of shear force versus diameter of the bonded area in order to determine the maximum force obtainable when shearing both gold and aluminum bonds having differing ball size. Interferences that may produce erroneous shear test results, such as friction rewelding of gold balls on gold metallization, are described along with ways of avoiding such problems. Finally, the implications of pending ASTM and military standards on the widespread use of the shear test is discussed. This paper is intended to present all information necessary to both understand and implement the shear test for research purposes or for production control.
[(301) 921-3621]

Other Semiconductor Metrology

Released for Publication

Forman, R.A. and Kratz, H.D., **A Simple Vacuum Pump Exhaust Filter**, submitted to Review of Scientific Instruments.

A simple high-throughput, exhaust filter for oil-filled mechanical vacuum pumps is described. The design allows easy connection to external systems. Inexpensive filter elements, available anywhere, are a further feature of the system.
[(301) 921-3625]

Galloway, K.F., **Measurements for VLSI Models**, to be published in Proc. Second International Workshop on Physics of Semiconductor Devices, Delhi, India, December 5-10, 1983.

The complexity of VLSI makes an experimental approach to design and fabrication unrealistic. Accurate, computer-based models for simulating processes, devices, and circuits are required to competitively develop VLSI technologies. The effectiveness of these models is often limited by the accuracy of the physical parameters used as input for the simulations. This paper summarizes results from two recent projects on measurement technology for obtaining parameters for VLSI models to illustrate the research in this area at the National Bureau of Standards.
[(301) 921-3541]

Hinkley, J.A., **Absorption of Polystyrene on Thermally Oxidized Silicon**, submitted to Polymer Preprints.

Ellipsometry was used to observe the adsorption, from θ solvents, of polystyrene on thermally oxidized silicon. Since no adsorption was seen with a polar solvent, it is concluded that specific acid-base interactions are decisive in adsorption. At high surface coverages, the present results agree with those on various metal surfaces, and the root-mean-square extension of polymer coils from the surface is almost twice the radius of gyration of a chain in solution.
[Contact: D.B. Novotny, (301) 921-3625]

Recently Published

Hinkley, J.A., **A Blister Test for Adhesion of Polymer Films to SiO_2**,

Other Semiconductor Metrology, cont'd.

Adhesion, 16, pp. 115-126 (December 1983).

Films of polystyrene or polymethyl methacrylate were cast on oxidized silicon substrates, then detached by the application of gas or water pressure from the back side of the film through a hole in the substrate. Critical detachment pressures showed good repeatability and could be used to calculate the work of adhesion. For polystyrene on a hydrophilic silica in the presence of water, the apparent work of adhesion is 78 mJ/m^2. Other polymer/substrate combinations gave meaningful variations in detachment pressure.
[Contact: D.B. Novotny, (301) 921-3625]

FAST SIGNAL ACQUISITION, PROCESSING, AND TRANSMISSION

Waveform Metrology

Recently Published

Andrews, J.R., Bell, B.A., and Baldwin, E.E., **Reference Flat Pulse Generator**, NBS Technical Note 1067 (October 1983).

A reference step-like pulse generator is described which has been developed at NBS. This generator can be used for accurately characterizing the step response of various kinds of transient recording equipment (oscilloscopes, waveform recorders, transient digitizers, etc). Basic design principles are given as well as complete circuit diagrams and descriptions. An analysis of the output stage of the generator is presented together with the circuit models for developing a time-domain computer simulation program using extended-SCEPTRE. Preliminary specifications indicate that the NBS Reference Flat Pulse Generator provides a negative-going reference transition duration (90 to 10 percent) of 600 ps, ±20 percent with baseline perturbations of less than ±2 percent for less than 5 ns.
[Contact: Miller, (303) 497-3131]

Lawton, R.A., **Photoconductive Switches Used for Waveform Generation at the National Bureau of Standards**, Proc. SPIE - The International Society for Optical Engineering, 439, pp. 88-94, SPIE, P.O. Box 20, Bellingham, WA, 98227 (1983) [conference San Diego, CA, August 24-26 1983].

Research in the measurement of pulse waveforms is being conducted at the National Bureau of Standards (NBS) in the characterization of waveform measurement systems and the development of reference waveforms. Efforts to upgrade the state of the art of fast waveform measurements at NBS has resulted in the development of the first photoconductive switch using GaAs in addition to a patent on the sampling of electrical signals with optical signals and vice versa. These photoconductive switches are now being applied to the development of reference waveform generators in the form of a Maxwell-Wagner two-layer capacitor in silicon stripline to complement the liquid-filled coaxial line filters developed previously. The silicon filters are more compact, rugged, and less expensive to fabricate. In addition, they lend themselves well to integration with photoconductive switches resulting in a reduction in connector problems and pulse excitation errors.
[(303) 497-3339]

Cryoelectronic Metrology

Recently Published

Sullivan, D.B., Radebaugh, R., Daney, D.E., and J.E. Zimmerman, **An Approach to Optimization of Low-Power Stirling Cryocoolers**, Proc. Second Biennial Conf. Refrigeration for Cryogenic Sensors, NASA Conf. Publication 2287, pp. 107-130, December 1983 [conference, Greenbelt, MD, December 7-8, 1982;

Cryoelectronic Metrology, cont'd.

abstract appeared on page 12 of July 1983 TPB (NBSIR 83-2719-3).

Zimmerman, J.E., Daney D.E., and Sullivan, D.B., **A Cryocooler for Applications Requiring Low Magnetic and Mechanical Interference**, Proc. Second Biennial Conf. Refrigeration for Cryogenic Sensors, NASA Conf. Publication 2287, pp. 95-106 (December 1983) [conference Greenbelt, MD, December 7-8, 1982].

A very low-power, low-interference Stirling cryocooler is being developed based on principles and techniques described in several previous publications over the last four years. It differs in several important details from those built previously. It uses a tapered displacer based upon an analytical optimization procedure. The displacer is driven by an auxiliary piston and cylinder (rather than by mechanical linkage) using some of the working fluid itself to provide the driving force. This provides smooth, vibration-free motion, and, more importantly, allows complete mechanical and spatial separation of the cryostat from the pressure-wave generator. Either of two different pressure-wave generators can be used. One is a non-contaminating, unlubricated ceramic piston and cylinder. The other is a compressed-air-operated rubber diaphragm with motor-driven valves to cycle the pressure between appropriate limits.
[(303) 497-3901]

Antenna Metrology

Released for Publication

Kanda, M., **Transients in a Resistively Loaded Loop Antenna**, paper to be given at 1984 IEEE Electromagnetic Compatibility Conference, Tokyo, Japan, October 1984, and published in Digest of that conference.

Transient characteristics of a loop antenna loaded uniformly with a resistive material are analyzed. The current distribution of the antenna is obtained by the use of the Fourier series expansion technique. It is found that the distortion of the transient waveforms due to a resonance of a loop antenna can be reduced and the received transient waveforms can be tailored by resistive loading.
[(303) 947-5320]

Recently Published

Greenlee, D.H., Kanda, M., and Chang, D.C., **The Characteristics of Iris-Fed Millimeter Wave Rectangular Microstrip Patch Antennas**, NBS Technical Note 1063 (October 1983).

The fabrication of various iris-fed millimeter-wave rectangular microstrip patch antennas is described. A model is proposed to describe the iris-fed antenna. Irises ranging in size from 15 percent of the area of the patch to the fully open waveguide are used to couple energy into the antenna. Resonance of the antenna is observed to be insensitive to the size of the iris for irises up to 115 percent of the size of the patch. A study is also made of the relationship of coupling to the antenna as a function of position of the iris with respect to the transverse plane of the waveguide, the iris always being centered with respect to the patch. In general, the antenna has a VSWR in the waveguide feed on the order of 5:1 at resonance, except for the fully open waveguide which gives rise to a VSWR of 2.9:1 at resonance. Far-field antenna power patterns are observed to be quite broad with H-plane beamwidths on the order of 130 degrees. Maximum antenna gain is seen to be 4.5 dB relative to an isotropic source (dBi), with 3 dBi typical. An initial study is made of the microstrip patch antenna fed from a longitudinal waveguide wall. Results indicate that this feed structure is likely to prove valuable for microstrip patch antennas with coupling at least as good as for the transverse-fed patch

Antenna Metrology, cont'd.

added to the possibility of feeding of multiple patches from a single waveguide.
[Contact: Kanda, (303) 497-5320]

Noise Metrology

Released for Publication

Counas, G.J., **NBS 2.0 GHz to 4.0 GHz Automated Radiometer Operation and Service Manual**, to be published as an NBSIR.

The equipment described by this manual is the 2.0 to 4.0 GHz subsystem of the automated radiometer. This section of the multiband automated radiometer is a coaxial total power radiometer which implements a six-port reflectometer for impedance characterization and correction and utilizes a newly developed broadband cryogenic noise standard. NBS noise measurement capability in this frequency band has been expanded by the addition of this system which adds continuous frequency coverage to existing services, along with the capability to measure cryogenic noise sources.
[(303) 497-3546]

Halford, D., **Transparent Metrology of Signal to Noise Ratios of Noise Band-Limited Digital Signals**, submitted to IEEE Trans. Communications.

We propose the use of a template method for quantitative, correct, and transparent measurement of signal power to additive noise power ratios (SNR) of digital signals and systems under full operating conditions. Outer guard chips of digital templates hold intersymbol interference fixed on inner target chips in realizations of the respective template patterns in traffic. The proposed template method needs to be developed and proven as a potentially valuable metrology capability; it can be especially important for real time, online performance assessment and monitoring of digital communication systems.

We define a correct measurement procedure as one actually measuring a specified parameter of interest of the specified signal, channel, device, or system. We define a transparent measurement procedure as one measuring the specified parameter without degradation of the usable channel capacity and without modification to or interference with the functioning of the measured system.

We discuss the significance of transparent metrology, the measurement of various SNRs by the template method, and the general applicability of the template method for measurements on any noisy digital signal. The template method can provide transparent metrology procedures for other basic measurands, e.g., intersymbol interference, multiplicative noises, and synchronization.
[(303) 497-5475].

Recently Published

Daywitt, W.C., **Design and Error Analysis for the WR10 Thermal Noise Standard**, NBS Technical Note 1071 (December 1983).

This note describes the design and error analysis of a WR10 thermal noise power standard. The standard is designed to operate at the boiling point of liquid nitrogen with a noise temperature accurate to ± 1 K.
[(303) 497-3720]

Optical Fiber Metrology

Recently Published

Chamberlain, G.E., Day, G.W., Franzen, D.L., Gallawa, R.L., Kim, E.M., and Young, M., **Optical Fiber Characterization -- Attenuation, Frequency-Domain Bandwidth, and Radiation Patterns**, NBS Special Publication 637, Vol. II (October 1983).

This is the second volume of a series intended to describe optical fiber measurement systems developed at the

Optical Fiber Metrology, cont'd.

National Bureau of Standards. The topics covered in this volume are attenuation, bandwidth (frequency domain), and near-field and far-field radiation patterns. Each chapter includes a tutorial section and a detailed description of the apparatus. The volume concludes with a glossary of optical communications terms.
[(303) 497-3706]

Kim, E.M., Franzen, D.L., Young, M., and Rodhe, P.M., **Estimating Index Profiles of 1.3-μm Single Mode Fibers by Near-Field Measurements at Blue Wavelengths**, IEEE J. of Lightwave Technology, LT-1, No. 4, pp. 562-566 (December 1983).

Near-field intensity measurements are obtained at the wavelength of 0.45 μm. At blue wavelengths, the fibers are sufficiently multimode so the near-field scan gives an approximation to the index profile. Near-field scans from six fibers are compared to actual index profiles as determined by the refracted ray method. Experimental near-field scans are also compared to theoretical predictions from a model using numerical solutions to the scalar wave equation.
[(303) 497-3897]

Other Fast Signal Topics

Recently Published

Johnson, E., **Simulating the Scratch Standards for Optical Surfaces -- Theory**, J. Applied Optics, 22, No. 24, pp. 4056-4068 (December 1983).

I show how to simulate the scattering generated by a scratch on the surface of high-quality optics and their elements. This is accomplished by first describing how the present cosmetic scratch standards tend to be used in the optics industry. Second, I derive from first principles, using the scalar model for electromagnetic radiation, the first-order scattering coefficients for the far-field radiation due to a particular scratch pattern. There are approximations made to get these coefficients. The results allow construction of a set of secondary scratch standards. These are a pattern of rectangular grooves that can be made precisely reproducible during the manufacturing phase. Appropriate selection from this set can provide the same range of scattering power and character as is present in the current scratch standards, which are not easily reproducible. Because the method for construction of these new secondary standards is nonrandom, to guarantee the reproducible construction between these standards it is necessary to restrict the observation range to 5 to 10 degrees from the direct beam.
[(303) 497-3234]

ELECTRICAL SYSTEMS

Power Systems Metrology

Recently Published

Hebner, R.E., **Development of Power System Measurements -- Quarterly Report January 1, 1983 to March 31, 1983**, NBSIR 83-2761 (October 1983).

This report documents the progress on five technical investigations sponsored by the Department of Energy and performed by or under a grant from the Electrosystems Division, the National Bureau of Standards. The work described covers the period January 1, 1983 to March 31, 1983. This report emphasizes the errors associated with measurements of electric and magnetic fields, the characteristics of corona in compressed SF_6 gas, and the measurement of the space charge density in transformer oil, the development of active insulators, and interfacial phenomena.
[(301) 921-3121]

Hebner, R.E., Kelley, E.F., FitzPatrick, G.J., and Forster, E.O., **The Effect of Impurities on Positive Streamer**

Power Systems Metrology, cont'd.

Propagation in n-Hexane, 1983 Annual Report, Proc. Conf. Electrical Insulation and Dielectric Phenomena, pp. 26-34 [conference Buck Hill Falls, PA, October 16-20, 1983].

This extended abstract of an oral presentation describes some effects of electrode geometry and chemical purity on the propagation of prebreakdown streamers in n-hexane. One impurity used was dimethylaniline (DMA), a material with low ionization potential, which produced a more hemispherical streamer than was observed in a pure fluid. In addition, the DMA also suppressed the transition to faster propagation modes. ASA-3, an antistatic additive which reduces the low-frequency conductivity, had little effect on the streamer propagation.
[(301) 921-3121]

Kelley, E.F. and Hebner, R.E., **Measurement of the Electric-Field in the Vicinity of an Oil-Pressboard Interface Parallel to the Field**, Proc. Conf. Interfacial Phenomena in Practical Insulating Systems, pp. 19-22 (December 1983) [conference Gaithersburg, MD, September 19-20, 1983].

Electro-optical Kerr-effect measurements are performed to measure the spatial variations of the electric field in transformer oil in a parallel-plate electrode system with and without a pressboard interface bridging the gap between the electrodes. No space-charge field enhancements are observed at room temperature (25°C) even with the interface present. At 125°C, space charge field enhancements are observed in transformer oil, but the field enhancement does not change upon the addition of an interface -- the field near the interface was the same as the field away from the interface to within the ±5% precision of the experiment.
[(301) 921-3121]

Misakian, M. and Fulcomer, P.M., **Measurement of Nonuniform Power Frequency Electric Fields**, IEEE Trans. Electrical Insulation, EI-18, No. 3, pp. 657-661 (December 1983) [abstract appeared on page 10 of April 1984 TPB (NBSIR 84-2857-2)].

Pulse Power Metrology

Released for Publication

Hebner, R.E., **The Measurement of High Current and Voltage Pulses**, to be published in Air Force Pulse Power Lecture Series.

This note introduces some of the fundamental approaches to the measurement of voltage or current pulses. The evaluation of the measurement process and the properties of selected devices -- resistive and capacitive probes, shunts, and transformers -- are highlighted. Electro-optical measurement of voltage and magneto-optical measurement of current are also discussed.

ELECTROMAGNETIC INTERFERENCE

Released for Publication

Bensema, W.D., **Personal FM Transceivers**, to be published as National Institute of Justice Standard 0209.01.

This document establishes minimum performance requirements and methods of test for frequency modulated personal transceivers and their associated antennas and power systems. The standard applies primarily to the law-enforcement community, and as such covers the four frequency bands 25-50 MHz, 150-174 MHz, 400-512 MHz, and 806-870 MHz.
[(303) 497-3465]

Kanda, M., **Time Domain Sensors and Radiators**, to be published as chapter in book, Time Domain Measurements in

Electromagnetic Interference, cont'd.

Electromagnetics, Ed. E.K. Miller, Van Nostrand Reinhold Co., Inc.

The purpose of this chapter is to discuss various sensors and radiators commonly used for time-domain antenna measurements. The sensors and radiators discussed here are passive, analog devices which convert the electromagnetic quantity of interest to a voltage or current at their terminal ports. Moreover, they are primary standards in the sense that their transfer functions can be calculated from their geometries and are flat (constant) across a wide frequency range.

For their usefulness in electric field strength measurements, linear antennas loaded non-uniformly and continuously with resistance, or both resistance and capacitance, are discussed. Also, a conical antenna and an asymptotic conical antenna are discussed from the standpoint of improved antenna characteristics. Various types of TEM horns are considered for improved directivity, e.g., a conducting TEM horn, and a resistively loaded TEM horn. For the magnetic field strength measurements, a loop antenna with uniform resistive loading is discussed.
[(303) 497-5320]

Wilson, P.F., Chang, D.C., and Ma, M.T., **Input Impedance of a Probe Antenna in a TEM Cell**, submitted to IEEE Trans. Electromagnetic Compatibility.

The input impedance of a probe antenna exciting a transverse electromagnetic (TEM) cell is formulated via a variational approach. The resulting impedance is shown to consist of two distinct terms: an ordinary rectangular waveguide contribution and a gap perturbation. Numerical results for both are given and suggest that a simple algebraic approximation for the input impedance should normally suffice. The resistive portion is found to be proportional to the square of the probe length, while the reactive portion is largely capacitive.
[(303) 497-3842]

CEEE CALENDAR

1984

April 30 - May 4 (Boulder, CO)

NBS Noise Measurement Seminar. The course is intended for practicing noise metrologists and technical managers responsible for systems for which accurate noise measurements are important. The seminar introduces and describes reference noise sources, noise measuring systems, and the problems of characterizing and measuring noise in passive components, amplifiers, and satellite earth terminals. Class examples will specifically address the measurement of noise power; amplifier noise; and antenna system noise, including measures such as noise equivalent flux, the ratio of system gain to system noise temperature G/T, and the ratio of carrier power to noise density C/kT.

The course will cover both theory and practice of precision noise measurements; the practical lectures are designed to stand alone and to be understood by those having minimal mathematical background.
[Contact: Sunchana Perera (303) 497-3546]

June 18-21 (Gaithersburg, MD)

Power Electronics Specialists Conference. Co-sponsored by the Power Electronics Council of the Institute of Electrical and Electronics Engineers and the National Bureau of Standards, the Conference is intended to provide a venue where specialists in circuits, systems, electron devices, magnetics, control theory, instrumentation, and power engineering may discuss new ideas, research, development, applications, and the

CEEE CALENDAR, cont'd.

latest advances in power electronics.

The Conference will incorporate six technical sessions (on converter circuits, converter systems, converter control, motor drives, power components, and modeling and analysis techniques), a one-day tutorial on Electromagnetic Compatibility in Power Systems, and three special "rap sessions" (EMI, RFI, and Noise: Fact or Fiction; Emerging Power Semiconductors: Positive and Negative Attributes; and Future Trends in Aircraft Power Electronics and Electrical Actuators).
[Contact: Sandra B. Kelley (301) 921-3541]

August 28-30 (Vail, CO)

Short Course on Optical Fiber Measurements. This course is addressed to scientists and engineers who are involved in fiber characterization. The course will emphasize concepts, techniques, and apparatus used in measuring the engineering parameters of telecommunication-grade fibers. A degree in electrical engineering or physics is assumed. The course will last three days with 18 hours of class time.
[Contact: Robert L. Gallawa (303) 497-3761]

October 15-17 (Boulder, CO)

Symposium on Optical Materials for High Power Lasers. The Symposium is the principal forum for the exchange of information on the physics and technology of materials for high-power lasers. Topics to be discussed include new materials, bulk damage phenomena, surface and thin film damage, design considerations for high-power systems, and fundamental mechanisms of laser-induced damage. The series of conference proceedings resulting from these annual symposia has collectively become the principal repository of information on optics for all aspects of high-power/high-energy lasers, including, in addition to the subjects given above, environmental degradation, durability, fabrication, material growth and deposition processes, and testing. [Contact: Aaron A. Sanders (303) 497-5341]

NEW STANDARD REFERENCE MATERIALS

Two new Standard Reference Materials (SRMs) for calibrating equipment used to make spreading resistance measurements have been released by the Semiconductor Materials and Processes Division to the NBS Office of Standard Reference Materials for sale to the public. SRM 2526 applies to (111)-oriented p-type silicon surfaces and SRM 2527 to $\overline{(111)}$-oriented n-type silicon surfaces. Each SRM consists of a set of about 15 specimens (number of specimens varies depending on availability of material of appropriate resistivities) of silicon, 6 x 12 mm in area and mounted on beveled metal blocks for convenient use in calibrating commercial spreading resistance equipment. These silicon chips have resistivities ranging from about 0.001 to 200 Ω•cm. Slices are measured before dicing; only slices having uniformity of resistivity within predetermined bounds are selected. The The uncertainties in resistivity range typically from 2 to 5 percent for p-type specimens and from 4 to 10 percent for n-type. Two companion SRMs for $\overline{(110)}$ silicon surfaces are about to be released (2528, p-type and 2529, n-type).

SPONSORS OF WORK REPORTED IN THIS ISSUE

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

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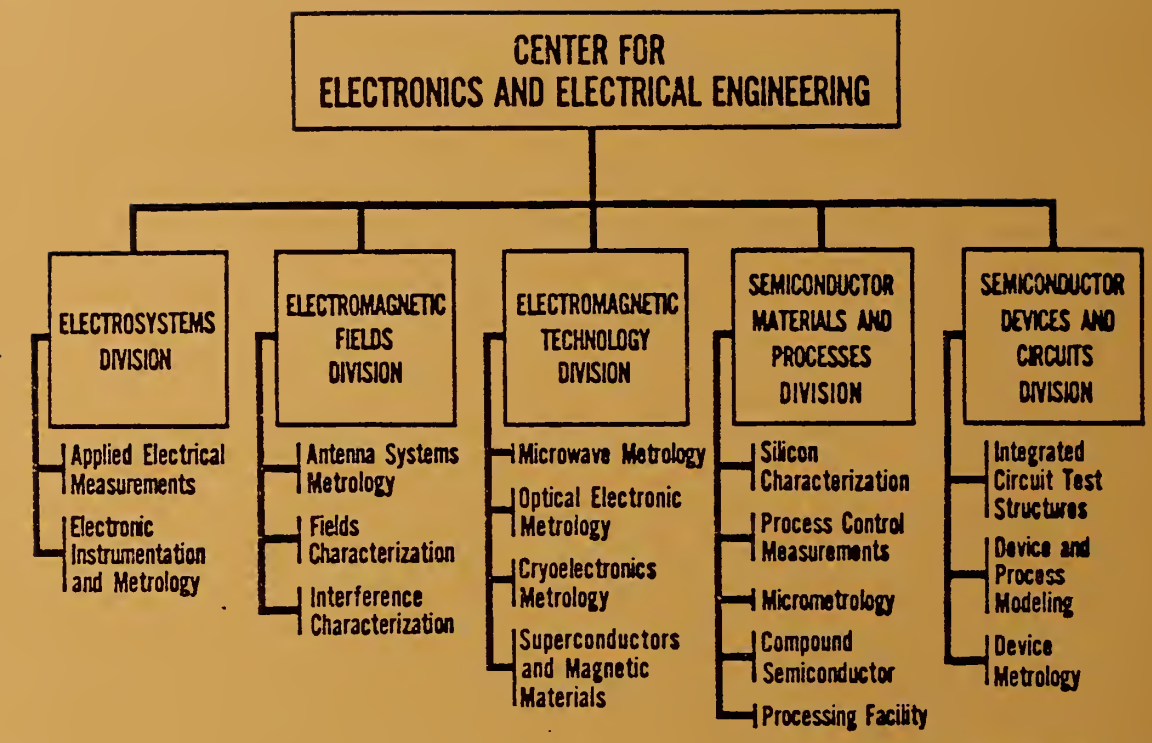

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KEY CONTACTS

Center (720)	
Director	Mr. Judson C. French (301) 921-3357
Deputy Director	Dr. Alvin H. Sher (301) 921-3357
Administrative Officer	Ms. Carol P. Mullis (301) 921-3357
Electrosystems Division (722)	
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INFORMATION:

For additional information on the Center for Electronics and Electrical Engineering, write to or call:

Center for Electronics and Electrical Engineering
National Bureau of Standards
Metrology Building, Room B-358
Gaithersburg, Maryland 20899

Telephone (301) 921-3357
USCOMM-NBS-DC